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Single night video-game use leads to sleep loss and attention deficits in older adolescents☆

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ABSTRACT

The present study investigated adolescent video-game use prior to bedtime and subsequent sleep, working memory and sustained attention performance. Participants were 21 healthy, good-sleeping adolescents (16 male) aged between 15 and 20 years ($M = 17.6$ years, $SD = 1.8$). Time spent video-gaming and subsequent sleep was measured across one night in the sleep laboratory. There were significant correlations between time spent video-gaming and sleep and between video-gaming and sustained attention, but not working memory. Sleep duration, in turn, had a significant negative association with sustained attention performance. Mediation analyses revealed that the relationship between video-gaming and sustained attention was fully mediated by sleep duration. These results indicate that video-gaming affected the ability to sustain attention only in as much as it affected sleep. In order to minimise negative consequences of video-game playing, video-games should be used in moderation, avoiding use close to the sleep period, to obviate detriments to sleep and performance.

Introduction

Video-gaming has widespread popularity among adolescents, with more than three quarters of U.S. children and adolescents playing video-games every week (Desai, Krishnan-Sarin, Cavallo, & Potenza, 2010). Despite their prevalence, the consequences of video-gaming to adolescent functioning are relatively under-studied and extant findings are inconsistent. Some studies have associated video-gaming with worse academic performance (Rehbein, Psych, Kleimann, Mediasci, & Mößle, 2010), memory deficits (Maass, Kollhörster, Riediger, Macdonald, & Lohaus, 2011), symptoms of inattention and ADHD (Chan & Rabinowitz, 2006), poor mood and heightened aggression. Conversely, other studies have found either no effect of video-gaming on academic performance (Gentile, Lynch, Linder, & Walsh, 2004; Smyth, 2007), or even beneficial associations between video-gaming and academic performance (Skoric, Teo, & Neo, 2009), working memory (Colzato, Van Den Wildenberg, Zmigrod, & Hommel, 2013), visual–spatial skills and attention (Ventura, Shute, & Zhao, 2013). It must be

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noted, however, that many of the studies showing improvements to performance use specialised educational or "brain-training" video-games that have been designed to improve a particular aspect of performance or cognition rather than traditional, recreational video-games (Ventura et al., 2013).

While the effects of video-gaming to adolescent daytime functioning and performance are unclear, there is more wide-spread concordance in the scientific literature, as well as among parents and educators, that video-gaming is associated with sleep difficulties. Previous research shows that video-gaming is associated with less total sleep (Adam, Snell, & Pendry, 2007; Shochat, Flint-Bretler, & Tzischinsky, 2010), later bedtimes (Adam et al., 2007), longer sleep onset times (Dworak, Schierl, Bruns, & Strüder, 2007; Gaina et al., 2005), later wake times (Shochat et al., 2010) and greater daytime sleepiness (Suganuma, Kikuchi, & Yanagi, 2007). Along with the growing proclivity of video-gaming has come an increasing presence of these technologies in adolescent bedrooms (Gradisar & Short, 2013). Simply the presence of technology in the bedroom has been associated with worse sleep in children and adolescents (Cain & Gradisar, 2010).

Recently, a model has been put forward to explain the complex interrelationships between technology use, individual differences, sleep and daytime impairments (see Fig. 1). According to this model, technology use can lead to poor or insufficient sleep via mechanisms including increased psychophysiological arousal, the displacement of bedtimes until later in the evening, exposure to bright light and night time waking. Impairments to sleep then lead to impairments of daytime functioning. Indeed, the findings that insufficient sleep leads to the same types of deficits attributed to video-gaming, such as memory deficits, difficulty sustaining attention, mood disturbances and worse cognitive and academic functioning (Beebe, Fallone, & Godiwala, 2008, Dagys et al., 2012) are consistent with this model. The model may also help to explain some of the variability in the literature regarding video-gaming and daytime functioning: namely, that the impact of video-gaming on performance may vary according to the degree to which video-gaming impacts upon sleep. As such, sleep can be argued to *mediate* the relationship between video-game use and daytime functioning.

When considering evidence for the theoretical pathway of video-gaming to sleep loss to impaired daytime functioning in the context of existing literature, the current literature is limited by large variations in regard to the operationalisation of "excessive" gaming, cross-sectional designs, and their reliance on subjective reports of video-gaming, sleep, and performance and daytime functioning. The present study extends previous work looking at the impact of video-gaming on daytime functioning by testing a mediation model using objective measures of video-gaming, sleep and performance in a controlled laboratory environment. It is hypothesised that the relationship between time spent video-gaming and next-day daytime functioning will be mediated by sleep. Specifically, it is hypothesised that greater time spent video-gaming will lead to less sleep and that this sleep reduction will, in turn, lead to diminished performance. The proposed mediation relationship is shown in Fig. 2. The daytime functioning variables tested include sustained attention and working memory.

Method

Participants

Twenty five adolescents participated in this study. Two participants were missing actigraphic data and two were missing sustained attention data, all due to technical difficulties with the devices. These participants were excluded from analyses,

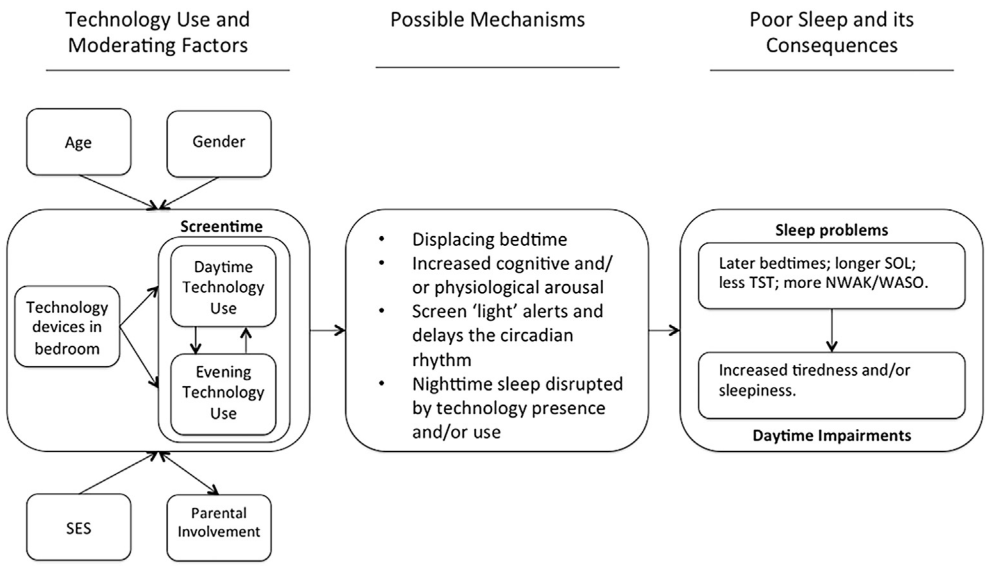

Fig. 1. The model of proposed relationships between technology use and sleep. Taken from Gradisar & Short.

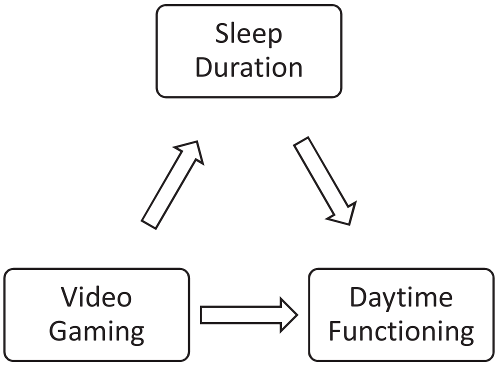

Fig. 2. Proposed mediation of time spent video-gaming and daytime functioning by sleep duration.

bringing the final sample size for these analyses to 21. The 21 participants (16 male) were aged between 15 and 20 years ($M = 17.6$, SD = 1.8). Participants were healthy, good sleepers, with normally entrained circadian rhythms, as determined by sleep midpoint on free days and questionnaire battery. They were non-smokers who consumed 3 or less caffeinated beverages per day, had not undertaken trans-meridian travel in the previous 3 months and were not taking medications known to affect sleep. Participants were not regular nappers, and they had regular sleep patterns, with bedtime occurring prior to 12midnight and wake times before 8:00 a.m. Participants' scores on each subscale of the Depression Anxiety Stress Scale (Lovibond & Lovibond, 1995) were within the normal range. Informed written consent was obtained from participants and, if under 18 years of age, a parent or guardian. This study was approved by the Flinders University Social and Behavioural Ethics Committee.

Measures

Video-gaming

A PlayStation 3 gaming console was used in conjunction with the video-game Bioshock Infinite (MA 15+). Bioshock Infinite is a narrative-driven, first-person shooter game. This game was chosen as it was a new-release game that participants had not played previously.

Sleep

In order to assess sleep-wake patterns, participants wore a MicroMini Motionlogger (Ambulatory Monitoring Inc.) activity monitor on their non-dominant wrist. Data were digitised in 1-min epochs using zero crossing mode with a sensitivity of .05 g. Actigraphy data were analysed with Action W2 software (AMI) using the Sadeh algorithm, which has been validated for use with adolescent populations (Sadeh, Sharkey, & Carskadon, 1994). Sleep onset was defined as the first of five consecutive epochs of sleep, and sleep offset as the last of three consecutive epochs of sleep. Sleep duration was calculated as the time elapsed from sleep onset to sleep offset. This calculation was used to avoid the underestimation of sleep duration and the over-estimation of wake after sleep onset that is found with actigraphic devices, especially among adolescents (Short, Gradisar, Lack, Wright, & Carskadon, 2012).

Performance

Working memory performance was measured using a computerised version of the Operation Span Task (OpSpan; Inquisit 4.0.3, Millisecond Software) (Gradisar, Terrill, Johnston, & Douglas, 2008). OpSpan is a dual procedure task that requires participants to shift attention between remembering a word and calculating mathematical equations. This task was originally designed for use with adults but has been customised for use with adolescents by simplifying words and mathematical problems. In a trial, alternating sets of words and mathematical equations are presented. In between each equation a word is presented for 1 s. At the end of each trial participants were required to indicate whether the equations were correct and then recall the target words. The first trial consisted of two equations and two words, with each subsequent trial increasing by one equation and one word to increase the load on working memory. Participants completed five trials, ranging from 2 to 6 equations to solve and words to be remembered. An accuracy of 85% required for the maths equations to ensure that participants were putting sufficient load on working memory by calculating the equation rather than simply guessing (in which case accuracy would be expected to be around 50%). Participants' scores could range from 0 to 20, with higher scores indicating better performance. The computerised version of OpSpan has been shown to correlate well with other measures of working memory capacity and has good internal consistency, Cronbach's alpha = .78 and test–retest reliability = .83 (Unsworth, Heitz, Schrock, & Engle, 2005). To account for individual differences in working memory capacity, the present study used difference scores for working memory by subtracting the morning OpSpan total score from the baseline total score. Positive scores indicate better working memory performance subsequent to video-game playing.

Psychomotor Vigilance Task (PVT) lapses have been shown to be a good measure of sustained attention and they are sensitive to sleep loss. In addition, the ability to sustain attention is important for a number of higher order cognitive functions (Lim & Dinges, 2010). Adolescents were required to fixate on a screen and respond to a visual stimulus as quickly as possible. Stimulus intervals range from 2 to 10 s and each test bout lasted for 10 min. Lapses were quantified as reaction times >500 ms. To account for individual differences in sustained attention performance, difference scores were calculated. The number of lapses on the morning subsequent to video-gaming was subtracted from baseline lapse performance (before video-gaming). Negative scores reflect worse sustained attention following a night of video-gaming. This measure has been successfully used in adolescents (Fallone, Acebo, Arnedt, Seifer, & Carskadon, 2001) and has good reliability and validity (Lim & Dinges, 2008).

Protocol

Participants arrived at the sleep laboratory at 7:00 p.m., having already consumed their evening meal. After practice testing, participants completed baseline measures of working memory and sustained attention. From 8:00 p.m. onwards, participants moved to their allocated sound-attenuated bedroom and began video-gaming. Participants who were still playing at 1:00 a.m. were asked to stop playing to ensure the opportunity for some sleep. Participants were aware that they would be woken at 7:00 a.m. for breakfast and performance testing the next morning. This simulates the week-night constraints of most adolescents, who have the opportunity to engage with technology in the evening, but who need to rise for school the next day.

Participants were under continuous behavioural observation via video cameras during video-gaming. The beginning of the sleep attempt was recorded by researchers who observed when each participant had ceased engaging with other activities, and lay down in bed with the lights off and their eyes closed. Participants' wore wrist actigraphy for the duration of their time in the laboratory. Participants were woken at 7:00 a.m. and given the opportunity to get ready for school, and to allow sleep inertia to subside. Between 7:30 a.m. and 8:15 a.m. participants completed tasks of working memory and sustained attention, and then departed the sleep laboratory.

Statistical analyses

The mediation models were tested using the procedure outlined by Baron and Kenny (1986). Before testing for mediation, the preconditions were examined to ensure that the mediator (sleep duration) was related to video-game playing time, difference in working memory performance and difference in sustained attention performance. To test for mediation, a simple regression assessed the relationship between video-game playing time and sustained attention. A hierarchical regression was then conducted, with sleep duration entered into the first step of the regression model, followed by video-gaming time. If the relationship between video-game playing time and sustained attention performance is fully mediated by sleep, we would expect that, after controlling for sleep duration, time spent playing video-games would no longer explain a significant amount of the variance in sustained attention performance.

Results

Table 1 shows descriptive statistics for video-gaming time, sleep duration, and performance measures, together with means and standard deviations for males and females and t-values for the difference between means. On average, participants spent just under 4 h gaming in one pre-bedtime session and obtained just under 7 h sleep. Males spent significantly more time gaming than females and they obtained significantly less sleep. Table 2 presents the Pearson correlation coefficients for the relationships between video-gaming, sleep duration, working memory, sustained attention, and age. Gaming explained a significant 84% of the variance in sleep duration, with longer video-game playing resulting in less sleep. Of interest, there was no significant relationship between gaming time and sleep onset latency ($r = -.15$), indicating that the effect of gaming on sleep duration occurred as a result of displacing sleep and not as a result of longer time taken to fall asleep. Together with the simple regression analysis, discussed subsequently, these results establish that the preconditions of mediation are only met for deficits of sustained attention. Results of Pearson correlations indicated that older adolescents spent significantly less time video-gaming and obtained significantly more sleep (see Table 2). However, as there were no

Table 1
Descriptive statistics for time spent playing the video-game, sleep duration, and sustained attention, together with statistics for males and females separately and t-values for the difference between males and females.

	Mean (SD)	Males	Females	t-value	Cohen's d
Gaming Time	3 h 46 min (1 h 15 m)	4 h 02 min (1 h 10 min)	2 h 45 min (1 h 07 min)	2.17*	−.22
Sleep Duration	6 h 48 min (1 h 20 m)	6 h 25 min (1 h 12 min)	7 h 58 m (1 h 23 m)	−2.43*	.30
Sustained Attention	.04 (1.80)	−.25 (1.91)	1.0 (1.41)	−1.34	.16

$p < .05$.

Table 2
Pearson correlations between gaming time, sleep duration, working memory, sustained attention and age.

	Sustained attention	Working memory	Sleep duration	Gaming time
Age	.27	.14	.49*	−.47*
Gaming time	−.46**	−.12	−.92***	
Sleep Duration	.47*	.04		
Working Memory	−.28			

***$p < .001$, **$p < .01$, *$p < .05$.

significant age or sex differences in measures of sustained attention or working memory, age and sex are not controlled in mediation analyses.

To test for mediation, simple and hierarchical regression analyses were conducted. In the simple regression, gaming time was regressed against sustained attention. Time spent video-gaming showed a significant negative relationship with sustained attention, $R^2 = .22$, $F(1,19) = 5.20$, $p = .034$, with longer time spent video-gaming resulting in greater decrements of sustained attention performance. Gaming time accounted for 22% of the variance in sustained attention. In the first step of the hierarchical regression, sleep time was regressed against sustained attention. Results reveal that sleep duration (the mediator) accounted for over 23% of the variance in sustained attention performance, $R^2 = .23$, $F(1,19) = 5.70$, $p = .028$. Gaming time was added in the second step to determine whether time spent gaming continued to explain a significant amount of the variance in sustained attention after controlling for sleep duration. Results revealed that, after controlling for the effect of sleep time, gaming time did not explain any additional variance in sustained attention performance, $R^2_{\text{change}} = .001$, $F_{\text{change}}(2,18) = .03$, $p = .86$, consistent with full mediation. Beta coefficients indicate that for every 90 minutes less sleep, lapses of sustained attention increased by 1 lapse per 10 min test bout.

Discussion

It was hypothesised that there would be a significant negative relationship between video-game use and working memory and sustained attention performance the next day, and that this relationship would be mediated by sleep. The findings of the present study support the mediation hypothesis in regard to sustained attention, but not working memory. It is possible that sustained attention performance is a more sensitive measure of sleep-related performance deficits when compared to working memory. This may be of particular relevance given that the adolescents in the current study were not severely sleep restricted. Normative sleep duration on school nights among Australian adolescents is estimated at just over 8 h sleep per night (Short, Gradisar, Lack, Wright, & Dohnt, 2013). In the present study, adolescents' average sleep duration was 6 h 48 min. While this is a marked reduction when compared to their average sleep, it does not indicate severe sleep restriction. As such, the degree of sleep loss may not have been sufficient to lead to performance deficits in metrics apart from those most sensitive to sleep loss, such as PVT lapses. In addition, the present study looked at the acute effects of one night of game playing. Within the home environment, the issue of chronicity is likely to be highly salient, with sleep debt accruing over subsequent nights of sleep restriction. Assessing the results of multiple nights spent gaming may provide a more ecologically valid protocol. When considering the existing literature on video-gaming and memory, Dworak et al. (2007) have shown that the use of video-games resulting in reduced sleep significantly diminished memory performance. However, this study only found decrements to verbal memory, but not spatial memory. As such, not all forms of memory may be influenced by video-games, which may account for the non-significant findings of this study.

Video-gaming had a large impact on subsequent sleep. There was a developmental aspect to this relationship, with younger adolescents gaming for longer and getting less sleep than older adolescents. This may reflect heightened risk-taking propensity in younger adolescents and highlights a greater risk for any ill-effects of prolonged gaming in this group. Shorter sleep durations, in turn, led to greater decrements of sustained attention. After controlling for sleep duration, gaming time had no significant relationship to sustained attention. This is consistent with the notion that video-gaming affects performance only in as much as it affects sleep. These results reveal that even one night of prolonged video-gaming can impact on next-day ability to sustain attention. The ability to sustain attention is crucial to the developing adolescent as it underpins a range of more complex, cognitive tasks (Whitney & Hinson, 2010). In the classroom, attentional lapses may negatively impact academic achievement, especially in test and exam situations (Fallone et al., 2001; Jiang et al., 2011). This may partially account for the previous findings linking video-game use to poor academic performance (Rehbein et al., 2010). The ability to sustain attention also has important real-world implications for adolescents in contexts such as learning to drive.

In order to isolate the effect of video-gaming on sleep and subsequent performance, this study was designed to control for the many extraneous, and often confounding factors that are present within the home environment (e.g., use of other technologies, caffeine use, parental monitoring (Short et al., 2011)). In doing this, however, the strength of the relationship between video-gaming and sleep likely exceeds that which would be found in the home setting. This study does, however, highlight an important consideration for future studies, namely, that the effect that technology use has on sleep is likely to be moderated by the time of day that the technology is being used. As such, a 2-h video-gaming session in the afternoon is much less likely to impact upon subsequent sleep than a 2-h session that starts in the late evening. In the earlier described model

examining causal mechanisms between technology use and insufficient or disturbed sleep, the mechanisms by which technology use may impact sleep include things such as bedtime displacement, light exposure, cognitive and physiological arousal, the effect of light to alert and possibly delay the circadian rhythms, and sleep disruption. All of these mechanisms rely upon the timing of technology use to be within a relatively close temporal proximity to the sleep period (or during the sleep period, in the case of sleep disruption) for these effects to take place. Thus, there may be a more complex relationship between video-game use and performance than that tested in this simple mediation model. It is possible that the time of day that adolescents play video-games moderates the relationship between game use and sleep duration (see Fig. 3), whereby the size of the relationship between video-game use and sleep duration is likely to be larger when video-games are played at times of day close to the sleep period. Conversely, video-game playing temporally distant from the sleep period may be associated with a small or even no relationship between game use and sleep. As such, protective factors to minimise the potential negative impacts of video-gaming to adolescent sleep and daytime functioning include no video-gaming in the period immediately before bedtime and removing technology from the bedroom environment. As younger adolescents were significantly more likely to video-game for longer and get less sleep, parental limit-setting around both bedtimes and video-gaming may be particularly important for children and younger adolescents (Short et al., 2011).

Strengths and limitations of the present study

A limitation of many tests of mediation models is the use of retrospective, cross-sectional data, thus limiting the ability to draw causal conclusions. A strength of the present study is the use of a design in which the dependent variable is preceded by the mediator, which, in turn, is preceded by the independent variable. As such, the temporal order strengthens the degree to which we can be confident about causation. The present study also expands on our understanding of the interrelationships between video-game use, sleep and daytime performance by testing a mediation model. Previous studies have largely focussed upon cross-sectional, bivariate relationships. In addition, this study offers further refinement to our understanding of these relationships, laying down the basis for testing a more complex model of moderated mediation.

An additional strength of the present study is the operationalisation of gaming time. In previous laboratory studies, gaming time has been fixed at a particular duration, often around 2 h, to be considered excessive gaming (Weaver, Gradisar, Dohnt, Lovato, & Douglas, 2010). However many adolescents are likely to play significantly more than this in a single playing session. The current study allowed participants play for as long as they desired, up to a maximum of 5 h, which may more accurately reflect their normative playing habits.

Despite the strengths of this study there are a number of limitations that must be acknowledged. Most notable is the sample of convenience and small sample size. Due to the nature of the study, adolescents who were more interested in gaming may be more likely to participate in the study. While this means that these results may not be generalisable to all adolescents in the community, they may accurately represent those adolescents who are frequent users of video-games. Secondly, laboratory studies such as this have difficulty in replicating a true gaming experience, reducing the ecological validity and generalisability of results. Results from a study by Smyth (2007) suggest that those playing online multiplayer games spent significantly longer gaming and experienced greater sleep problems. Additionally, emotional attachment to a game may become greater with more gaming time. As such, the one night of playing time included in the present study may not be sufficient to develop an emotional attachment.

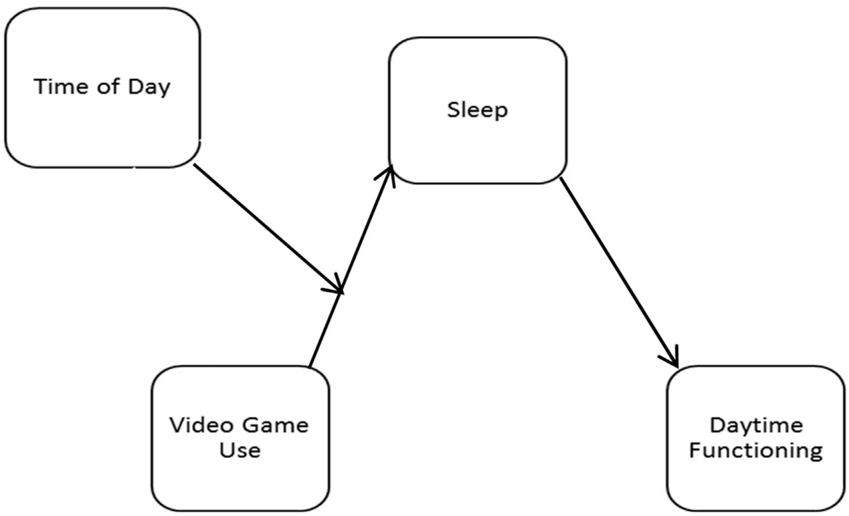

Fig. 3. The proposed moderated mediation between video-games, sleep, performance and time of day.

Concluding remarks

The present study showed the significant impact of a single night of adolescent video-game use on sleep and sustained attention, but not working memory. Results of mediation analyses were consistent with the full mediation of the relationship between video-gaming time and sustained attention performance via sleep duration. This suggests that while longer time spent video-gaming at night leads to diminished sustained attention in the morning, the casual mechanism occurs through the effect that video-gaming has on sleep duration. These results highlight the potential performance deficits associated with evening gaming, especially if repeated on consecutive nights, which may have important consequences in domains such as school achievement and accident risk. In order to minimise potential negative consequences of video-game playing, video-games should be used in moderation and not too close to the sleep period, in order to avoid harmful effects to sleep and performance.

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